The correlation of black hole mass with metallicity index of host spheroid

Shota Kisaka⋆, Yasufumi Kojima† and Yosuke Otani
Department of Physics, Hiroshima University, Higashi-Hiroshima, 739-8526, Japan

6 August 2008

ABSTRACT

We investigate the correlation between the mass of the supermassive black holes (SMBHs) and metal abundance, using existing data sets. The SMBH mass M_{bh} is well correlated with integrated stellar feature of Mgb. For 28 galaxies, the best-fit M_{bh}-Mgb relation has a small scatter, which is an equivalent level with other well-known relation, such as a correlation between the stellar velocity dispersion and the mass. An averaged iron index $\langle Fe \rangle$ also positively correlates with M_{bh}, but the best-fit M_{bh}-$\langle Fe \rangle$ relation has a larger scatter. The difference comes from the synthesis and evolution mechanisms, and may be important for the SMBH and star formation history in the host spheroid.

Key words: black hole physics – galaxies:bulges – galaxies:abundances.

1 INTRODUCTION

Recent observations of nearby massive spheroids (ellipticals, lenticular and spiral bulges) have established that supermassive black holes (SMBHs) are present in the nuclei of galaxies. The mass M_{bh} of SMBHs ranges from 10^6 to $10^9 M_\odot$. Several statistical correlations with characteristic parameters of the host spheroids are explored: relation with the luminosity L(Kormendy & Richstone 1995; Marconi & Hunt 2003; Graham 2007), the mass M_s of the spheroids(Magorrian et al. 1998; Häring & Rix 2004), the stellar velocity dispersion σ(Gebhardt et al. 2000; Ferrarese et al. 2000; Tremaine et al. 2002), the light concentration or Sérsic index n (Graham et al. 2001; Graham & Driver 2007), gravitational binding energy E_g (Aller & Richstone 2007) and so on. The recent updated survey for various galaxy parameters is given in Aller & Richstone (2007). If the fitting models are good, the correlations may provide some clues to the coevolution of SMBHs and the host spheroids. Some tentative theories have been proposed to clarify the origin of these correlations, e.g., Silk & Rees (1998); Umemura (2001).

The galaxies have some aspects as an assemble of stars, gases and dark matters. The quantities M_s, σ, E_g represent the dynamical aspect, while L, n represent the photometric one, although they are closely related each other. Very little attention is paid to the chemical one. The observation is not so easy and therefore the correlation between SMBH mass and spheroid chemical property is not well studied so far. Both the metal abundance and black hole mass increase with time and we therefore expect some correlations between them. It is important to clarify the correlation, and the extent, if any. The chemical parameter using Lick/IDS absorption line indices, e.g., Worthey et al. (1994), especially Mg and Fe is systematically studied in literatures(Trager et al. 2000; Denicoló et al. 2005; Kuntschner et al. 2006) for the galaxies in which presence of SMBH is reliable. Using the published data, we investigate the correlation with SMBH mass in this paper.

As a sample we select only 28 galaxies, for which SMBH masses are measured by dynamical methods. In section 2, we describe the sample of galaxies and criterion of our choice. In section 3, we derive the correlation between M_{bh} and σ, and that between M_{bh} and the B-band magnitude M_B from our sample. These correlations are known to be good, and are used in order to check no serious bias involved in the sample. Our results for M_{bh}-σ and M_{bh}-M_B relations are not so different from those by Aller & Richstone (2007); Graham (2007), although the source sample is not the same. We also show the correlation between black hole mass and metal abundance index using our sample. Finally, a discussion of our results is given in section 4.

⋆ E-mail:kisaka@theo.phys.sci.hiroshima-u.ac.jp
† E-mail:kojima@theo.phys.sci.hiroshima-u.ac.jp

2   THE SAMPLE

TABLE 1 Galaxy Parameter Used in The Fits

Galaxy	Type[a]	M_{bh} (low,high) ($M_\odot$)	Reference	σ[b] (km s^{-1})	M_B [c] (mag)	Mgb (mag)	$\langle Fe \rangle$ (mag)	Reference
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
NGC 221	S0	2.5E6 (2.0,3.0)	1	75	-15.3	0.099 ± 0.001	0.078 ± 0.001	19,20
NGC 224	Sb	1.4E8 (1.1,2.3)	2	160	-19.0	0.175 ± 0.002	0.087 ± 0.001	20
NGC 821	E4	8.5E7 (5.0,12)	3	209	-20.4	0.159 ± 0.002	0.086 ± 0.001	19,20,21
NGC 1023	SB0	4.4E7 (3.9,4.9)	4	205	-18.4	0.162 ± 0.003	$\cdots$	21
NGC 2974	E4	1.7E8 (1.5,1.9)	5,6	233	-20.9	0.159 ± 0.002	0.084 ± 0.002	19,21
NGC 3115	S0	1.0E9 (0.4,2.0)	7,8	230	-20.2	0.177 ± 0.002	0.096 ± 0.001	19,22
NGC 3245	S0	2.1E8 (1.6,2.6)	9	205	-19.6	0.161 ± 0.006	0.077 ± 0.002	19
NGC 3377	E5	1.0E8 (0.9,1.9)	10	145	-19.0	0.142 ± 0.002	0.076 ± 0.001	19,20,21
NGC 3379	E1	1.4E8 (0.6,2.0)	11	206	-19.9	0.168 ± 0.001	0.084 ± 0.001	19,20,21
NGC 3384	SB0	1.6E7 (1.4,1.7)	10	143	-19.0	0.154 ± 0.002	0.075 ± 0.001	19,21
NGC 3414	S0	2.5E8 (2.2,2.8)	5,6	205	-20.0	0.170 ± 0.003	0.081 ± 0.001	19,21
NGC 3608	E2	1.9E8 (1.3,2.9)	10	182	-19.9	0.162 ± 0.002	0.085 ± 0.001	19,20,21
NGC 4261	E2	5.2E8 (4.1,6.2)	12	315	-21.1	0.186 ± 0.002	0.088 ± 0.001	19,20
NGC 4374	E1	4.6E8 (2.8,8.1)	13,14	296	-21.4	0.168 ± 0.001	0.082 ± 0.002	19,21,22
NGC 4459	S0	7.0E7 (5.7,8.3)	15	186	-19.1	0.139 ± 0.003	$\cdots$	21
NGC 4473	E5	1.1E8 (0.3,1.5)	10	190	-19.9	0.168 ± 0.002	0.088 ± 0.002	21,22
NGC 4486	E0	3.0E9 (2.0,4.0)	7,16,17	375	-21.5	0.199 ± 0.002	0.086 ± 0.002	21,22
NGC 4552	E	5.0E8 (4.5,5.5)	5,6	252	-19.2	0.185 ± 0.002	0.084 ± 0.001	20,21
NGC 4564	S0	5.6E7 (4.8,5.9)	10	162	-17.4	0.173 ± 0.003	$\cdots$	21
NGC 4596	SB0	7.8E7 (4.5,11.6)	15	152	-20.6	0.150 ± 0.008	$\cdots$	23
NGC 4621	E5	4.0E8 (3.6,4.4)	5,6	211	-19.5	0.178 ± 0.002	0.088 ± 0.002	21,22
NGC 4649	E1	2.0E9 (1.4,2.4)	10	385	-21.3	0.194 ± 0.002	0.085 ± 0.001	20
NGC 4697	E4	1.7E8 (1.6,1.9)	10	177	-20.2	0.146 ± 0.002	0.078 ± 0.001	20
NGC 5813	E1	7.0E8 (6.3,7.7)	5,6	230	-20.9	0.167 ± 0.001	0.078 ± 0.001	19,20,21
NGC 5845	E3	2.4E8 (1.0,2.8)	10	234	-18.7	0.169 ± 0.003	0.093 ± 0.002	19,21
NGC 5846	E0	1.1E9 (1.0,1.2)	5,6	238	-21.2	0.179 ± 0.001	0.085 ± 0.001	19,20,21,22
NGC 7052	E4	3.3E8 (2.0,5.6)	7,18	266	-21.2	0.182 ± 0.002	0.080 ± 0.002	20
NGC 7457	S0	3.5E6 (2.1,4.6)	10	67	-17.0	0.101 ± 0.003	$\cdots$	21

NOTES.-Col.(1):Galaxy name. Col.(2):Galaxy type. Col.(3):SMBH mass. Col.(4):Reference for col.(3). Col.(5):Effective stellar bulge velocity dispersion. Col.(6):Absolute bulge B-band magnitude. Col.(7),(8)Line strength index measurements of the luminosity weighted spectrum within $r_e/8$ for the Mgb and $\langle Fe \rangle$ indices. Col.(9):Reference for col.(7),(8).

[a]Morphological type from NED except for NGC 224 and NGC 4564. The type given here for those galaxies is from Graham (2002) for NGC 221, and from Trujillo et al. (2004) for NGC 4564.

[b]The value is taken from Tremaine et al. (2002) except for NGC 2974, NGC 3414, NGC 4552, NGC 4621, NGC 5813, NGC5846 Hu (2008), NGC 4374 Marconi & Hunt (2003).

[c]The value is taken from Graham (2007) or extracted from Marconi & Hunt (2003) and the Third Reference Catalogue of Bright Galaxies de Vaucouleurs et al. (1991).

REFERENCES.-(1)Verolme et al. (2002) (2)Bender et al. (2005) (3)Richstone et al. (2004) (4)Bower et al. (2001) (5)Cappellari et al. (2007) (6)Hu (2008) (7)Tremaine et al. (2002) (8)Kormendy et al. (1996) (9)Barth et al. (2001) (10)Gebhardt et al. (2003) (11)Shapiro et al. (2006) (12)Ferrarese, Ford & Jaffe (1996) (13)Maciejewski & Binney (2001) (14)Kormendy et al. (2001) (15)Sarzi et al. (2001) (16)Harms et al. (1994) (17)Macchetto et al. (1997) (18)van der Marel & van den Bosch (1998) (19)Denicoló et al. (2005) (20)Trager et al. (2000) (21)Kuntschner et al. (2006) (22)Howell (2005) (23)Peletier et al. (2007)

Our sample consists of 28 nearby galaxies, which are listed in Table 1. We put two criteria to pick up the sample from literatures. First, the BH masses are measured by good spatial resolution. The sources are limited to $M_{bh} > \sigma^2 r_{res}/(2G)$, where σ^2 is stellar velocity dispersion, r_{res} the instrumental spatial resolution. This condition is used by e.g., Marconi & Hunt (2003); Hu (2008). Second, metal indices of Mg or Fe are measured. Most of our sample corresponds to that of Tremaine et al. (2002). 21 galaxies are drawn from their table and 7 galaxies are added: NGC 2974, NGC 3414, NGC 4552, NGC4621, NGC 5813 and NGC5846 from Cappellari et al. (2007); Hu (2008), and NGC 4374 from Maciejewski & Binney (2001). The masses of SMBHs are updated for 3 galaxies, NGC 224(Bender et al. 2005), NGC 821(Richstone et al. 2004) and NGC 3379(Shapiro et al. 2006). The galaxy morphology class is also listed in Table 1 from the NASA Extragalactic Database (NED). However, some corrections are added to the data: NGC 4564(Trujillo et al. 2004) and NGC 221(Graham 2002) are now recognized as S0 galaxies. In Table 1, effective velocity dispersion σ is tabulated as an indicator of the dynamical parameter of spheroids. Following Tremaine et al. (2002), the relative errors in σ are estimated as 5 % (0.021 dex). As the photometric parameter of spheroids, the B-band magnitude M_B is tabulated. Following Graham (2007), the relative errors in M_B are 0.3

mag. For the chemical parameter of spheroids, we use spectral absorption line indices in the visual as defined by the Lick group, e.g., Burstein et al. (1984); Faber et al. (1985). Lick indices have proven to be a useful tool for the derivation of ages and metallicity of unresolved stellar populations(Denicoló et al. 2005). In this paper, we use Mgb, Fe5270, Fe5335 indices, measuring respectively the strength of MgI at $\lambda \simeq 5156-5197$Å, FeI at $\lambda \simeq 5246-5286$Åand FeI at $\lambda \simeq 5312-5352$Å. These indices in mag are calculated by the standard equations:

$$EW_{mag} = -2.5 \log \left\{ \frac{\int_{\lambda_1}^{\lambda_2} [F(\lambda)/C(\lambda)] d\lambda}{\lambda_2 - \lambda_1} \right\}, \tag{1}$$

where

$$C(\lambda) = F_b \frac{\lambda_r - \lambda}{\lambda_r - \lambda_b} + F_r \frac{\lambda - \lambda_b}{\lambda_r - \lambda_b} \tag{2}$$

and λ_b and λ_r are the mean wavelength in the blue and red pseudo-continuum intervals, respectively. We have adopted the spectral pseudocontinua and band passes of the Mgb, Fe5270, Fe5335 Lick/IDS indices defined in Worthey et al. (1994). We use a combined "iron" index, $\langle \text{Fe} \rangle$ defined by

$$\langle Fe \rangle \equiv \frac{1}{2}(Fe5270 + Fe5335). \tag{3}$$

This index has smaller random error than either that of Fe5270 or that of Fe5335 (Gorgas, Efstathiou & Aragon-Salamanca 1990). These index values used from the literatures, are the measurements within the central region $r < r_e/8$, where r_e is effective radius of the spheroids. The properties of the spheroids and SMBHs are listed with their references in Table 1.

3 RESULTS

In order to fit the data to the linear relation $y = a + bx$, we use a version of the routine FITEXY (Press et al. 1992) modified by Tremaine et al. (2002). Novak et al. (2006) showed that this algorithm is the most efficient and least biased among a set of algorithms explored by them. The best-fit values a and b are calculated from data $(x_i, y_i)(i = 1, \cdots, N)$ by minimizing the quantity

$$\chi^2 = \sum_{i=1}^{N} \frac{(y_i - a - bx_i)^2}{\delta y_i^2 + \epsilon^2 + b^2 \delta x_i^2}, \tag{4}$$

where δx_i and δy_i are the measurement uncertainty in x_i and y_i. We use a constant value of 5 % (0.021 dex) for velocity dispersion σ, and 0.3 mag for the B-band magnitude M_B. The uncertainty for the metal abundance is listed in Table 1, and is used for each source. The intrinsic scatter ϵ in the linear relation is calculated when the reduced chi-squared value $\chi^2/(N-2)$ is equal to 1, after many trails to fit it for various ϵ. The upper and lower uncertainties of ϵ are estimated by the values for $\chi^2/(N-2) = 1 \pm \sqrt{2/N}$.

3.1 Dynamical and Photometric Properties

In order to check the dependence on the sampling data, we derive M_{bh}-σ and M_{bh}-M_B relations from our sample. First, for the dynamical aspect, we show a relation between the SMBH mass and the stellar velocity dispersion derived from Table 1. Our result of M_{bh}-σ relation is given by

$$\log(M_{bh}/M_\odot) = (3.98 \pm 0.35) \log(\sigma/200) + 8.23 \pm 0.06 \tag{5}$$

with $\epsilon = 0.25^{+0.06}_{-0.03}$dex in $\log M_{bh}$. This relation is consistent with previous relations. For example, recent updated one by Aller & Richstone (2007) using a sample of 23 galaxies is

$$\log(M_{bh}/M_\odot) = (3.79 \pm 0.32) \log(\sigma/200) + 8.16 \pm 0.06 \tag{6}$$

with $\epsilon = 0.23$ dex. Figure 1 shows our M_{bh}-σ relation (5) in comparison with (6).

Next, for the photometric aspect, we derive the M_{bh}-M_B relation. Our result is

$$\log(M_{bh}/M_\odot) = (-0.42 \pm 0.05)(M_B + 19.5) + 8.14 \pm 0.08 \tag{7}$$

with $\epsilon = 0.36^{+0.07}_{-0.05}$dex[1] Graham (2007) obtained

$$\log(M_{bh}/M_\odot) = (-0.40 \pm 0.05)(M_B + 19.5) + 8.27 \pm 0.08 \tag{8}$$

---

[1] We have also derived the relation of M_{bh} with the K-band magnitude, but there is no significant difference in the scatters of both relations.
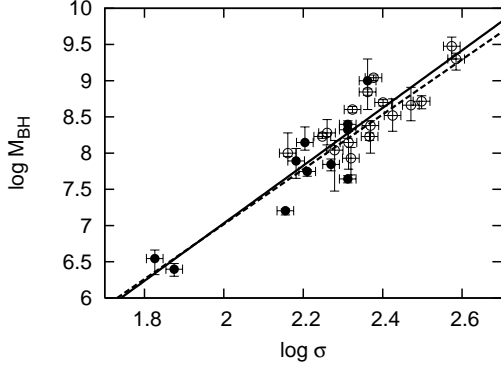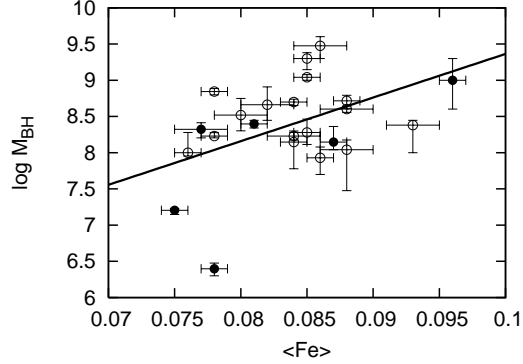
Figure 1. Relationship between SMBH mass and effective stellar velocity dispersion for 28 galaxy samples. The solid line represents our best fit relation (5). For a comparison, the relation by (Aller & Richstone 2007) is shown by a dashed line. Elliptical galaxies are denoted by open circles, lenticulars and spirals by filled circles.
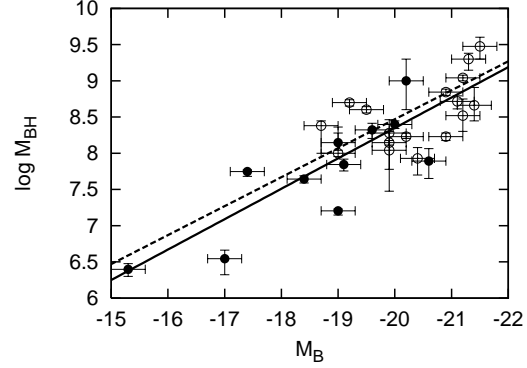
Figure 2. Relationship between SMBH mass and absolute B-band luminosity of the spheroid for 28 galaxy samples. The solid line represents our best fit relation (7). For a comparison, the relation found by (Graham 2007) is shown by a dashed line. The symbols are the same as Figure 1.
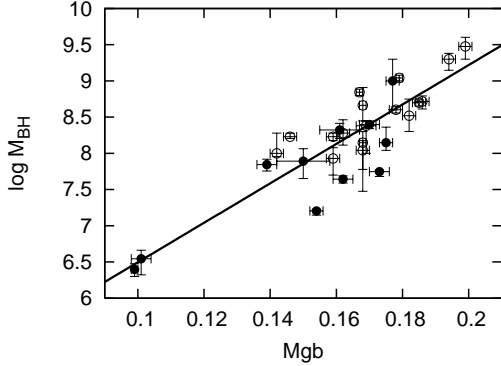
Figure 3. Relationship between SMBH mass and Mgb index value within a circular aperture of $r_e/8$ for our samples. The symbols and line are the same as in Figure 1.

Figure 4. Relationship between SMBH mass and $\langle Fe \rangle$ index within $r_e/8$ for our samples. The symbols and line are the same as in Figure 1.

with $\epsilon = 0.30^{+0.04}_{-0.05}$dex. Although intrinsic scatter in our relation is a little high, both two relations agree within the uncertainties. Both relations (7) and (8) are plotted in Figure 2. By comparing with previous results, we may say that there is no serious bias in our sampling data.

3.2 Chemical Property

In Figure 3, we plot M_{bh} as a function of the integrated stellar feature of Mgb for the 28 galaxies. It is found that the mass M_{bh} significantly correlates with the index Mgb. The best fit relation is obtained as

$$\log(M_{bh}/M_\odot) = (27.23 \pm 3.00)(Mgb - 0.16) + 8.13 \pm 0.07 \tag{9}$$

with $\epsilon = 0.32^{+0.06}_{-0.04}$dex. The scatter is not so bad as that of well-fitted M_{bh}-σ and M_{bh}-M_B relations. The index Mgb is a good indicator, but other indicator of the metal abundance is not so good. We have tested the correlation with different index. For instance, we show M_{bh} as a function of $\langle Fe \rangle$ index in Figure 4. The best fit relation is

$$\log(M_{bh}/M_\odot) = (60.25 \pm 26.01)(\langle Fe \rangle - 0.083) + 8.34 \pm 0.13 \tag{10}$$

with $\epsilon = 0.58^{+0.12}_{-0.07}$ dex. This relation has much larger scatter than that of eqs.(5)-(9). It is clear from Figure 4 that the index $\langle Fe \rangle$ is not good one. Summarizing the relationships obtained in our own study, we find that M_{bh}-σ is the best, M_{bh}-Mgb and M_{bh}-M_B are moderate, and M_{bh}-$\langle Fe \rangle$ is the worst.

4 DISCUSSION

We have shown that a good correlation between SMBH mass and Mgb index value. The best-fitting M_{bh}-Mgb relation has small intrinsic scatter 0.32 dex which is comparable one in other strong correlations found so far. Such a new correlation in

the chemical aspect is expected through other relations in dynamical/photometric aspects. The metal abundance is roughly correlated with total stellar mass, absolute magnitudes etc. e.g., Pagel (1997). In particular, there is a remarkably tight relation between Mg_2 and the central velocity dispersion of stars(Terlevich et al. 1981; Bender et al. 1993). The positive correlations have been found between some quantities characterizing the hosts and SMBH mass. A positive correlation is also suggested between the SMBH mass and the metallicity derived from emission line ratios in 578 AGNs spanning a wide range in redshifts(Warner, Hamann & Dietrich 2003). Our result of Mgb for nearby galaxies is more tight. Thus, positive correlation is expected, but the degree was not clear beforehand. It was not clear which indicators of the metal abundance strongly correlate with the SMBH mass. The index ⟨Fe⟩ correlates with it, but the intrinsic scatter is not so small as that of Mgb. Heavy elements Mg and Fe are synthesized by two different types of supernovae (Type Ia and II), with different time scales. This evolutionary difference causes the scatter in the correlations.

The growth of black hole mass is mainly determined by the accretion rate and the lifetime of the activity. The environmental factors near the central region of galaxies may partially be affected by some global quantities, such as the mass and size of the host. If the mass M_{bh} of SMBH is determined solely by the spheroid mass M_s as $M_{bh} = \varepsilon M_s$ ($\varepsilon \sim 10^{-5}$), then we have $M_{bh} \propto M_s \propto L \propto \sigma^4$, where we assume that a constant mass-to-light ratio and the Faber-Jackson relation in elliptical galaxies hold in the spheroids. The features in the host spheroids are transferred to the relations with the black hole mass, M_{bh}-L and M_{bh}-σ relations. Other features in the hosts, binding energy, light concentration and so on also give some relations with M_{bh}. Bender et al. (1993) discuss that the strength of Mg_2 is determined not only by the global mass M_s, but also by the local stellar density, which is related with the star-formation rate etc. It is therefore important to examine the correlation of M_{bh} with the other physical quantities of the spheroid, in addition to M_s. The metal abundance is a tracer for integrated stellar populations. The tight relation M_{bh}-Mgb, which is discovered here but is still tentative, may be useful for the better understanding of the coevolution of SMBH and host spheroid, if it is not accidental. Further work is needed to clarify whether this relation is fundamental or not.

REFERENCES

Aller, M. C., & Richstone, D. C. 2007, ApJ, 665, 120
Barth, A. J., et al. 2001, ApJ, 555, 685
Bender, R., Burstein, D. & Faber, S. M., 1993, ApJ, 411, 153
Bender R., et al. 2005, ApJ, 631, 280
Bower, G. A., et al. 2001, ApJ, 550, 75
Burstein, D., Faber, S. M., Gaskell, C. M., & Krumm, N. 1984, ApJ, 287, 586
Cappellari, M., et al. 2007, astro-ph/0709.2861, in Bureau M., Athanassoula E., Barbuy B., eds, Proc. IAU Symp. 245, Formation and Evolution of Bulges. Cambridge Univ. Press, Cambridge, in press
de Vaucouleurs, G., de Vaucouleurs, A., Corwin, H. G., Jr., Buta, R. J., Pasturel, G., & Fouqué, P. 1991, Third Reference Catalogue of Bright Galaxies (New York: Springer)
Denicoló, G., et al. 2005, MNRAS, 356, 1440
Faber, S. M., Friel, E. D., Burstein, D., & Gaskell, C. M., 1985, ApJS, 57, 711
Ferrarese, L., & Merritt, D. 2000, ApJ, 539, L9
Ferrarese, L., Ford, H. C., & Jaffe, W. 1996, ApJ, 470, 444
Gorgas, J., Efstathiou, G., & Aragon-Salamanca, A. 1990, MNRAS, 245, 217
Graham, A. W., Erwin, P., Caon, N., & Trujillo, I., 2001, ApJ, 563, L11
Graham, A. W. 2002, ApJ, 568, L13
Graham, A. W. 2007, MNRAS, 379, 711
Graham, A. W., & Driver, S. P. 2007, ApJ, 655, 77
Gebhardt, K., et al. 2000, ApJ, 539, L13
Gebhardt, K., et al. 2003, ApJ, 583, 92
Häring, N., & Rix, H.-W. 2004, ApJ, 604, L89
Harms, R. J., et al. 1994, ApJ, 435, L35
Howell, J. H. 2005, AJ, 130, 2065

Hu, J. 2008, MNRAS, 386, 2242

Kormendy, J., & Richstone, D. 1995, ARA&A, 33, 581

Kormendy, J., et al. 1996, ApJ, 459, L57

Kormendy, J., & Gebhardt, K. 2001, in Martel, H., Wheeler, J. C. eds, The 20th Texas Symposium on Relativistic Astro-
   physics. Am. Inst. Phys., New York, 586, 363

Kuntschner, H., et al. 2006, MNRAS, 369, 497

Macchetto, F., et al. 1997, ApJ, 489, 579

Maciejewski, W., & Binney, J. 2001, MNRAS, 323, 831

Magorrian, J., et al. 1998, AJ, 115, 2285

Marconi, A., & Hunt, L. K. 2003, ApJ, 2003, 589, L21

Novak, G. S., Faber, S. M., & Dekel, A. 2006, ApJ, 637, 96

Pagel, B. E. J. 1997, Nucleosynthesis and Chemical Evolution of Galaxies (Cambridge: Cambridge Univ. Press)

Peletier, R. F., et al. 2007, MNRAS, 379, 445

Press, W. H., Teukolsky, S. A., Vetterling, W. T., & Flannery, B. P. 1992, Numerical Recipes (2nd ed.; Cambridge: Cambridge
   Univ. Press)

Richstone, D., et al. 2004, ApJ, submitted (astro-ph/0403257)

Sarzi, M., et al. 2001, ApJ, 550, 65

Shapiro, K. L., et al. 2006, MNRAS, 370, 559

Silk, J., & Rees, M. J. 1998, A&A, 331, L1

Terlevich, R., Davies, R. L., Faber, S. M. & Burstein, D. 1981, MNRAS, 196, 381

Trager, S. C., Faber, S. M., Worthey, G., & González, J. J. 2000, AJ, 119, 1645

Tremaine, S., et al. 2002, ApJ, 574, 740

Trujillo, I., Erwin, P., Asensio Ramos, A., & Graham, A. W. 2004, AJ, 127, 1917

Umemura, M. 2001, ApJL, 560, L29

van der Marel, R. P., & van den Bosch, F. C., 1998, AJ, 116, 2220

Verolme, E. K., et al. 2002, MNRAS, 335, 517

Warner, C., Hamann, F., & Dietrich, M. 2003, ApJ, 596, 72

Worthey, G., Faber, S. M., & González, J. J., Burstein, D. 1994, ApJS, 94, 687